Impacts of Anthropogenic NOx and VOC Emissions Change on Surface Ozone in East Asia: the Effects of Long-range Transport and Domestic Sources

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Outline

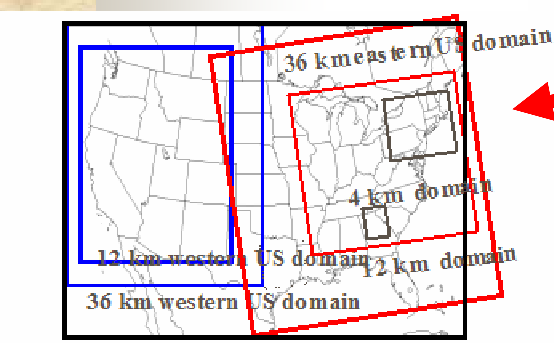
- Follow up the HTAP Meeting at Jülich and Hanoi in November, 2007
- Influences Effects of SR Cases (by areas in East Asia and Megacities)
- The Issue of Downscaling Process for Initial & Boundary Conditions in Vertical Layers
- Summary

Modeling domains

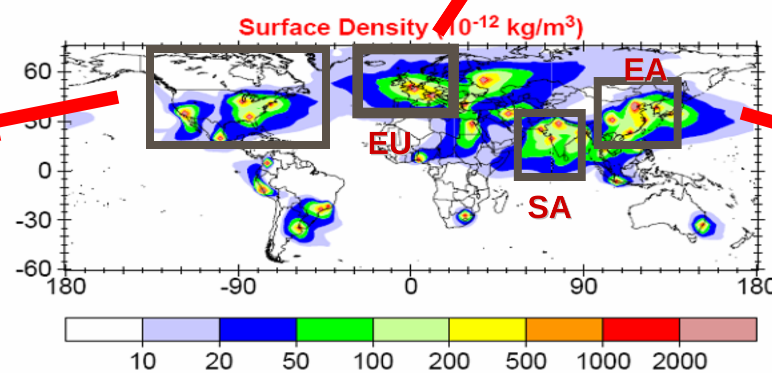
Regional Modeling Domains:

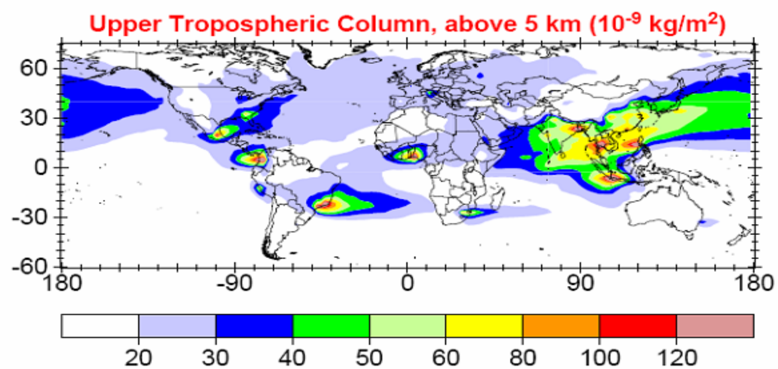
EU, SA, EA

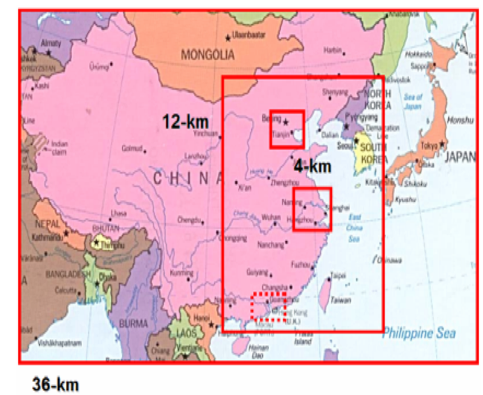
Urban Domains: mega-cities



36 km Annual National US domain







HTAP SR Scenarios in East Asia

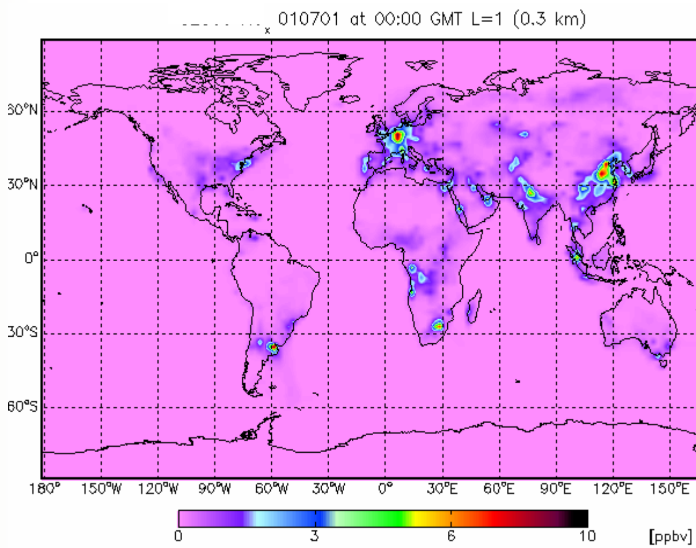
- SR1: Base-case simulation for year 2001
- SR3EU: Anthropogenic NOx emissions reduced 20% over Europe
- SR3SA: Anthropogenic NOx emissions reduced 20% over South Asia
- SR3NA: Anthropogenic NOx emissions reduced 20% over North America
- SR3local: Anthropogenic NOx emissions reduced 20% over East Asia
- SR6EU: Combined reduction of anthropogenic emissions(NOx/NMVOC/CO/SO2/NH3/POM/EC) by 20% over Europe
- SR6SA: Combined reduction of anthropogenic emissions by 20% over South Asia

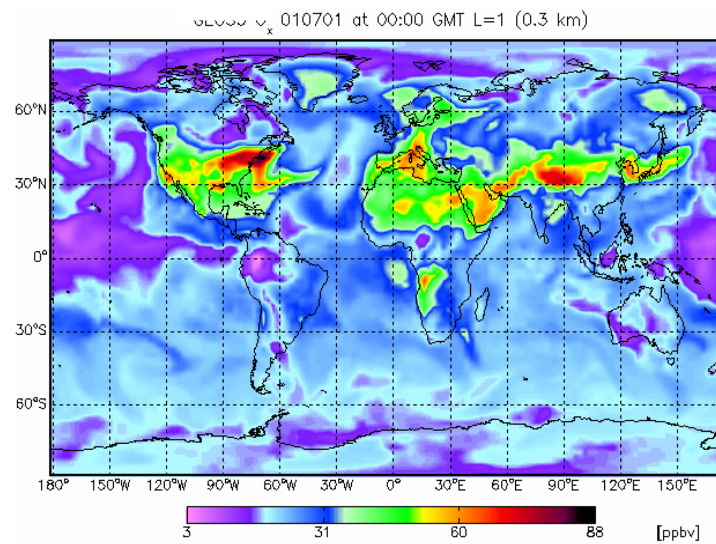
SR6NA: Combined reduction of anthropogenic emissions by 20% over North America

- SR6local: Combined reduction of anthropogenic emissions by 20% over East Asia

GEOS-Chem Configurations

- **Domain:** Global
- **Horizontal Grid Spacing:** 2° x 2.5°
- **Horizontal Coordinate:** Lat x Lon
- **Vertical Grid Spacing:** 30 layers
- **Simulation Period:** 2001, 2002
- **Meteorological Input:** GEO3, GEO4





East Asia Regional Modeling Configurations

- **Features : Models-3/CMAQ One-Atmosphere (multi-pollutants) Modeling**
  - 2001 January, April and July scenarios
  - 36-km East Asia CMAQ Domain in Lambert Conformal projection
- **Model Setup :**
  - NASA's TRACE-P and updated emission inventories and local emissions and GEIA/MODIS biogenic emission inventory
  - Emissions Processing: Spatial allocation (GIS/Gridding) and Temporal, speciation needed for the M3/CMAQ simulations
  - 36-km and 14 vertical layers
  - Meteorology : MM5 V3.7
  - CMAQ V.4.6
  - Chemical mechanism: CB-IV
  - Initial and Boundary Conditions: GEOS-Chem

Models-3/CMAQ Study Domains

- East Asia (36-km)

- Beijing region
- Shanghai region
- Wulumuqi
- Chengdu
- Taipei
- PRD region
- Tokyo
- Seoul

36-km

Transport Impacts in Megacities :

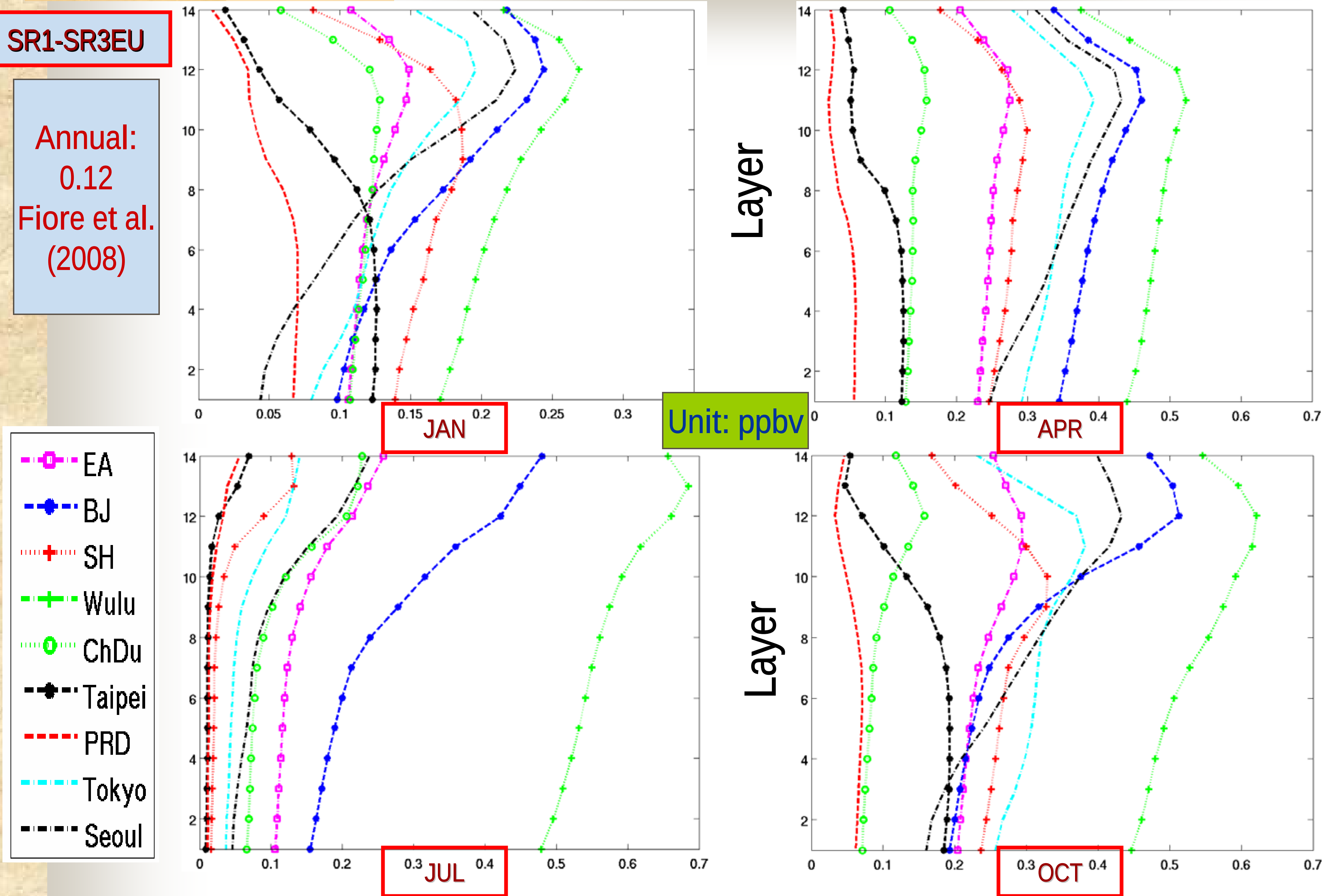
between the base case and control cases

- Case1: SR1 - SR3EU (NOx 20% reduction)
- Case2: SR1 - SR3SA (NOx 20% reduction)
- Case3: SR1 – SR3NA (NOx 20% reduction)
- Case4: SR1 – SR3local (NOx 20% reduction)
- Case5: SR1 - SR6EU (Anthropogenic 20% reduction)
- Case6: SR1 - SR6SA (Anthropogenic 20% reduction)
- Case7: SR1 - SR6NA (Anthropogenic 20% reduction)
- Case8: SR1 – SR6local (Anthropogenic 20% reduction)

EU (20% NOx Reduction) Influences to EA (AVERAGE)

SR1-SR3EU

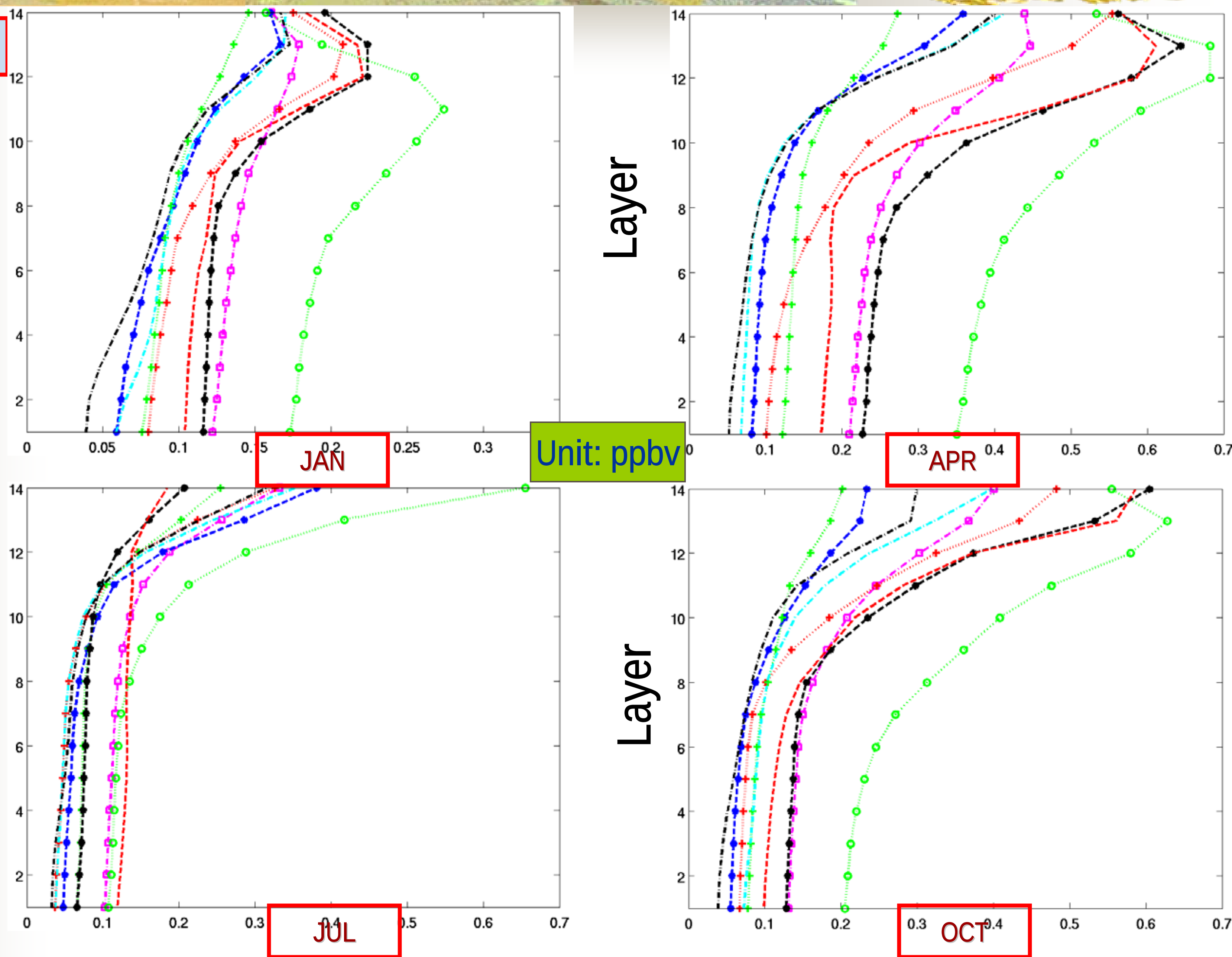
Annual: 0.12
Fiore et al. (2008)

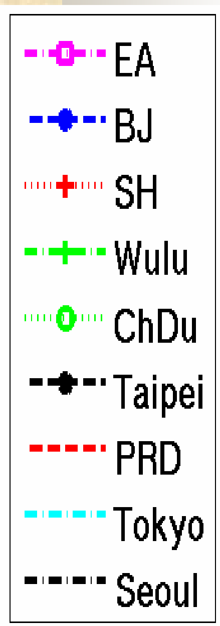


SA (20% NOx Reduction) Influences to EA (AVERAGE)

SR1-SR3SA

Annual:
0.10
Fiore et al.
(2008)

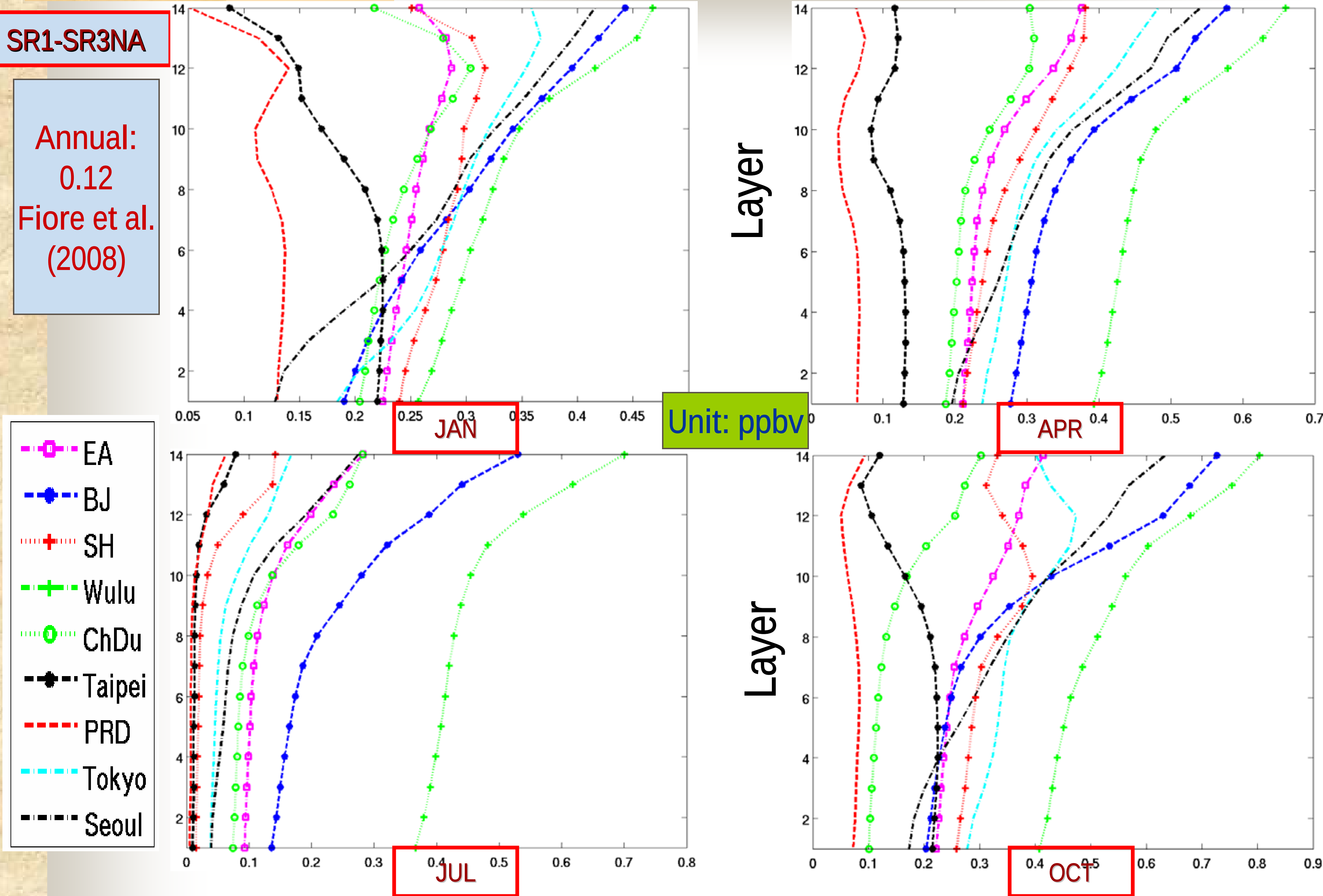




NA (20% NOx Reduction) Influences to EA (AVERAGE)

SR1-SR3NA

Annual: 0.12 Fiore et al. (2008)

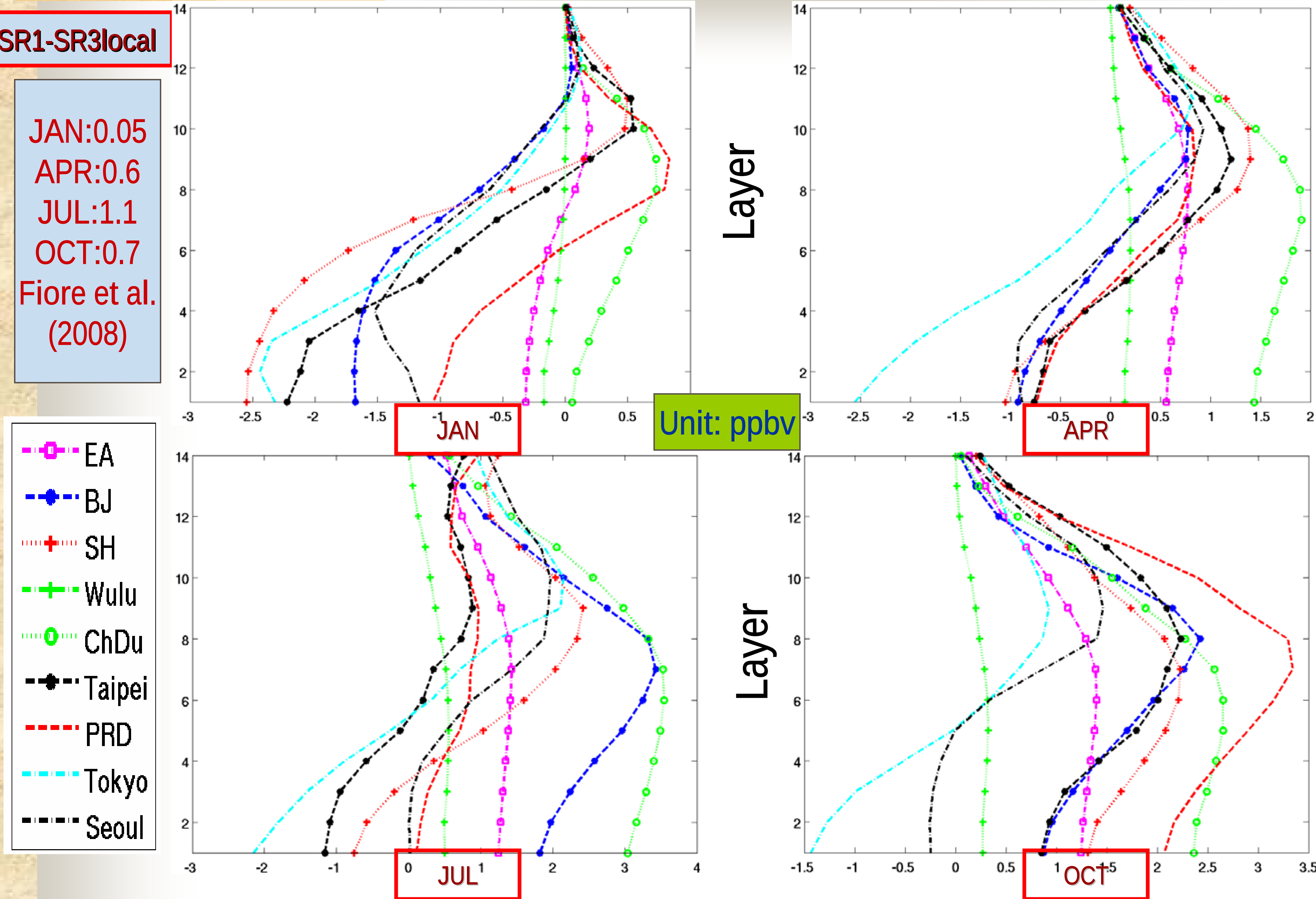


Local (20% NOx Reduction) Influences to EA (AVERAGE)

SR1-SR3local

JAN:0.05
APR:0.6
JUL:1.1
OCT:0.7
Fiore et al. (2008)

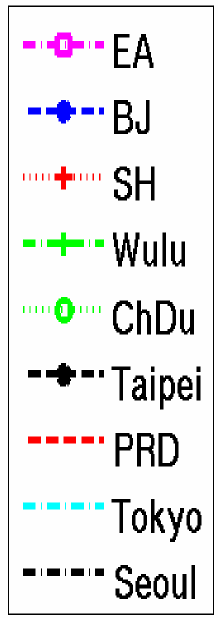
Unit: ppbv

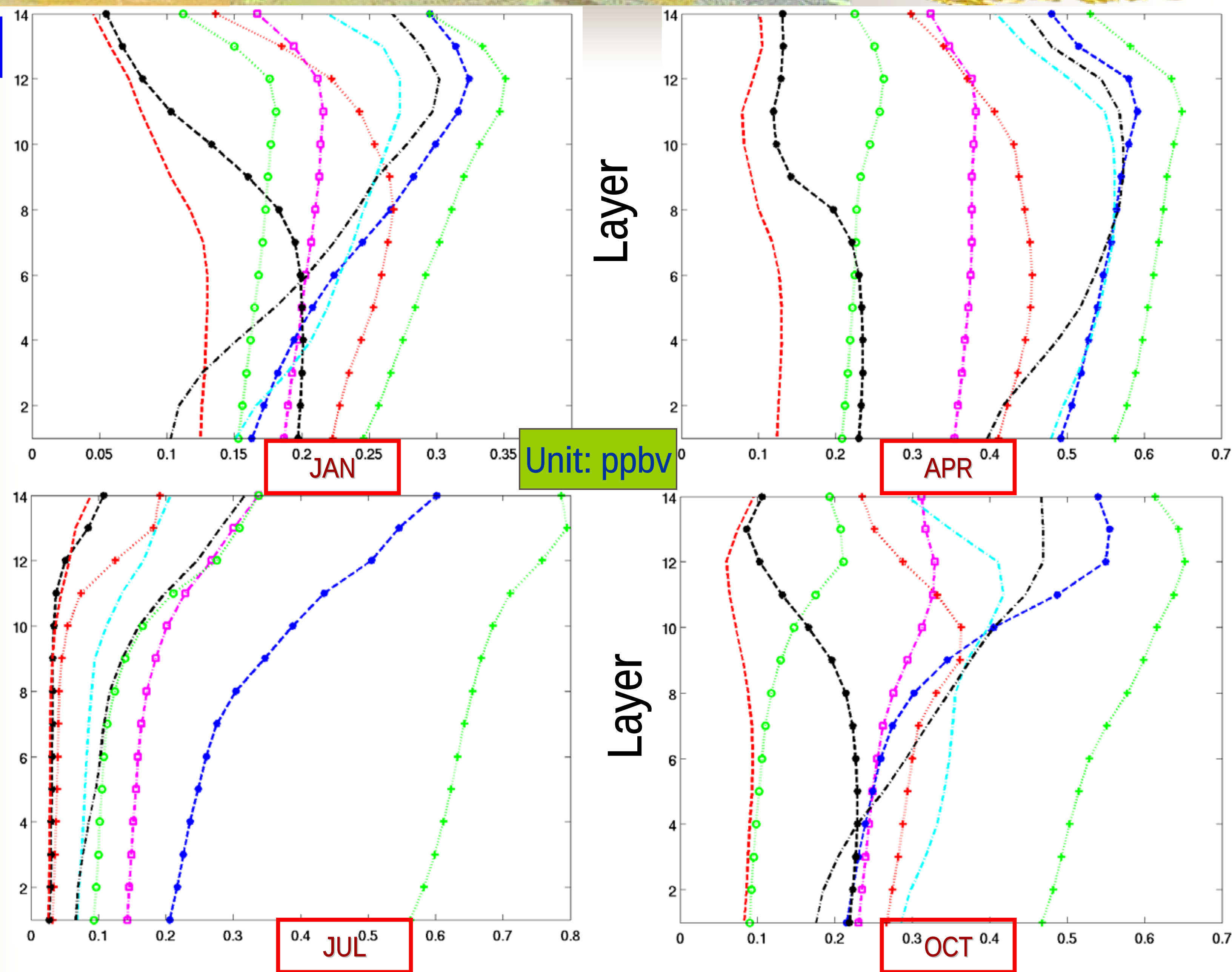


EU (20% Anth. Reduction) Influences to EA (AVERAGE)

SR1-SR6EU

JAN:0.2
APR:0.4
JUL:0.1
OCT:0.25
Fiore et al. (2008)



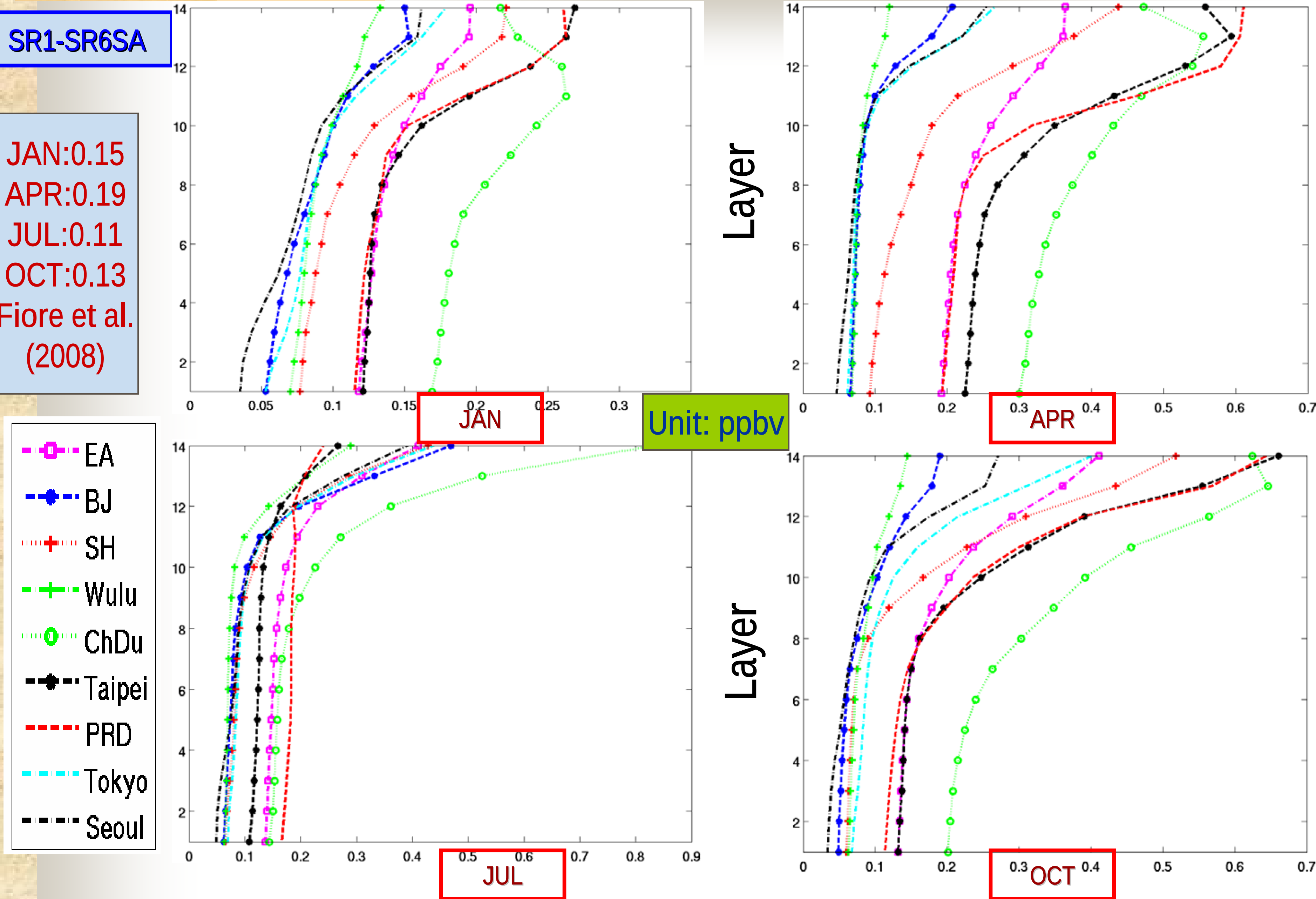


SA (20% Anth. Reduction) Influences to EA (AVERAGE)

SR1-SR6SA

JAN:0.15
APR:0.19
JUL:0.11
OCT:0.13
Fiore et al. (2008)

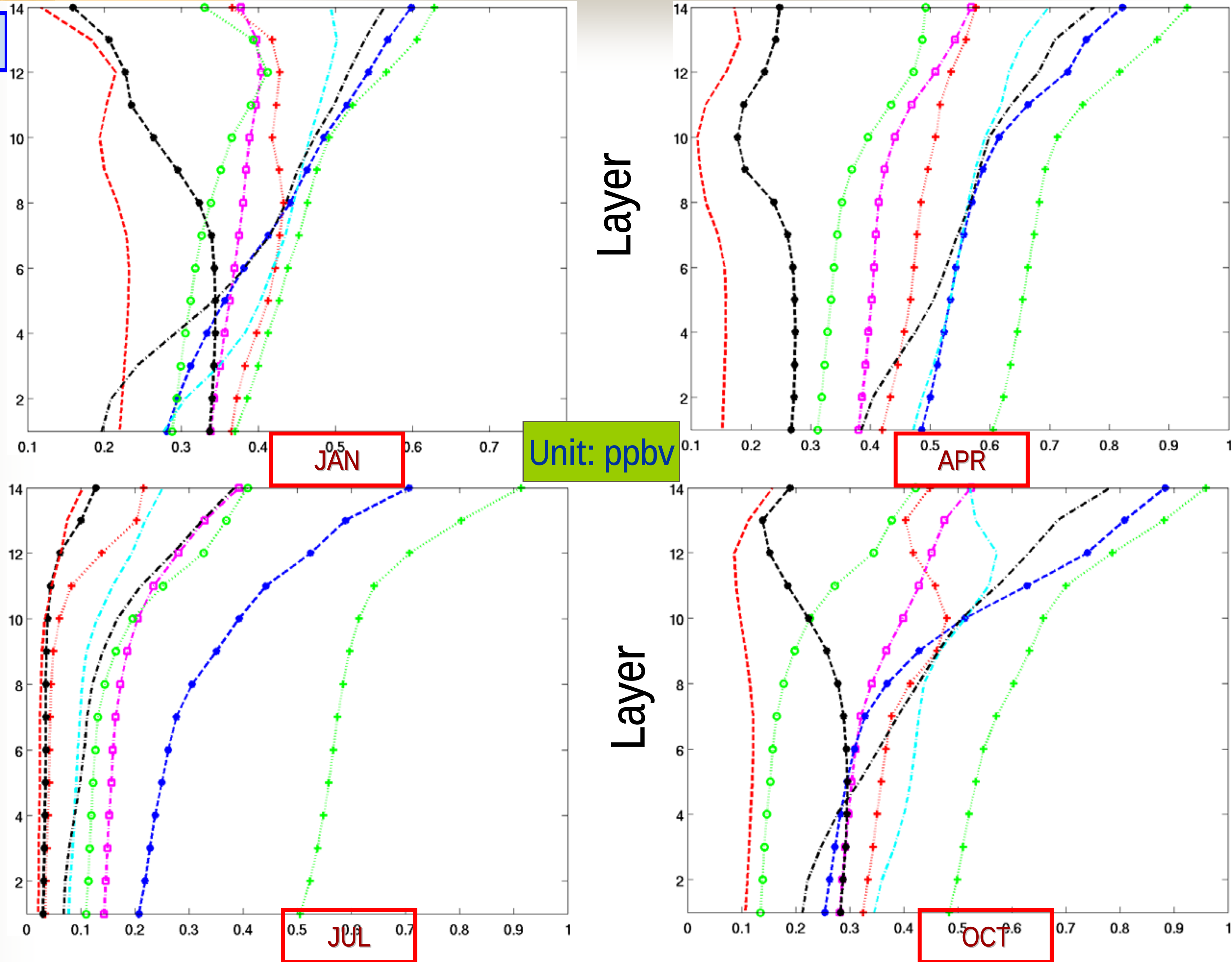
Unit: ppbv

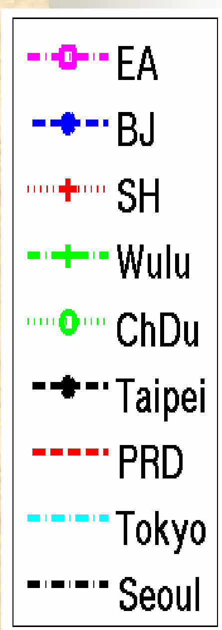


NA (20% Anth. Reduction) Influences to EA (AVERAGE)

SR1-SR6NA

JAN:0.26
APR:0.28
JUL:0.1
OCT:0.25
Fiore et al. (2008)

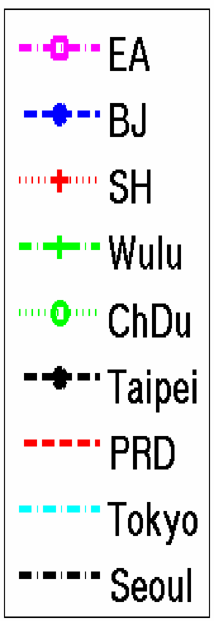


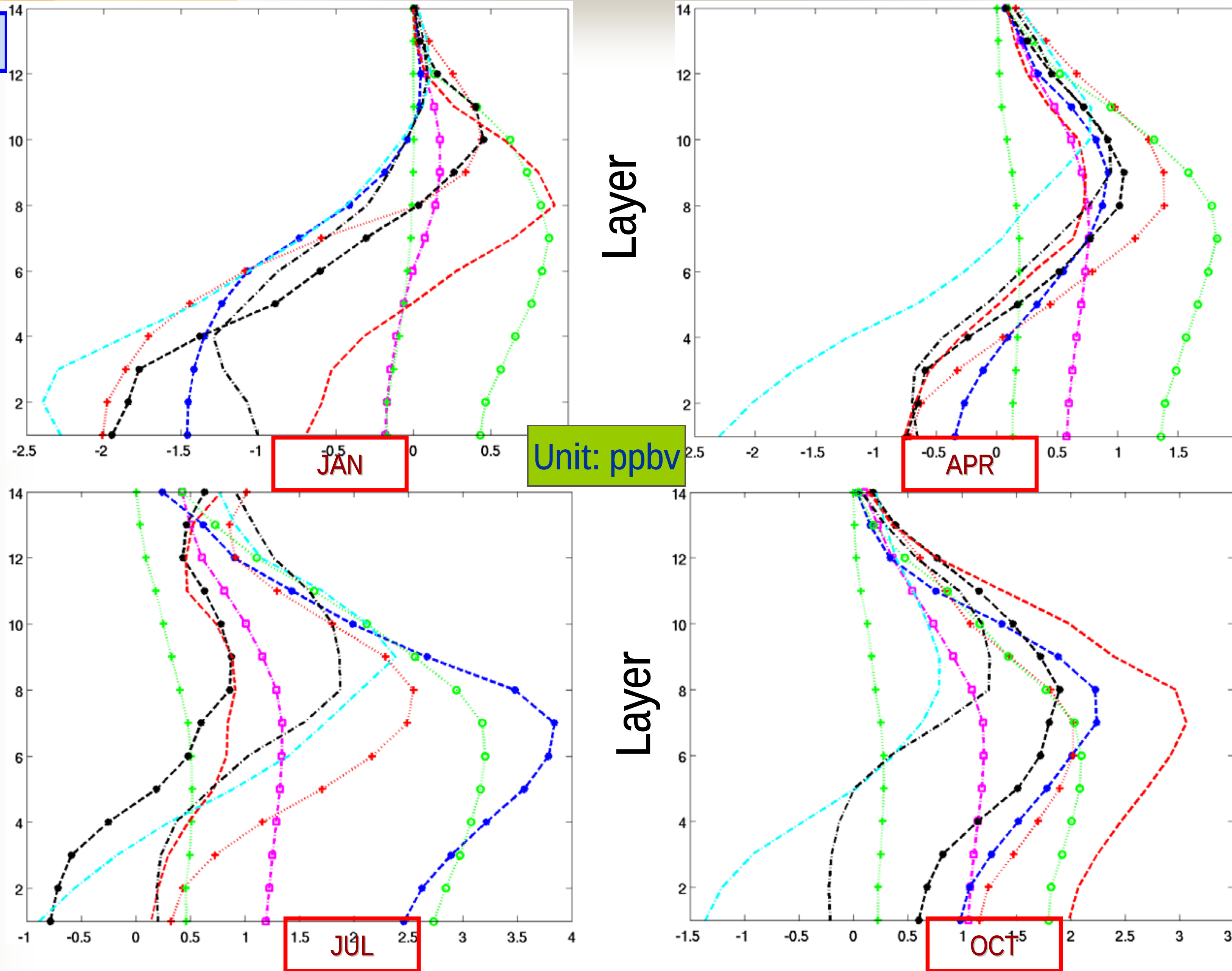


Local (20% Anth. Reduction) Influences to EA (AVERAGE)

SR1-SR6local

JAN:0.4
APR:0.9
JUL:1.3
OCT:1.0
Fiore et al. (2008)



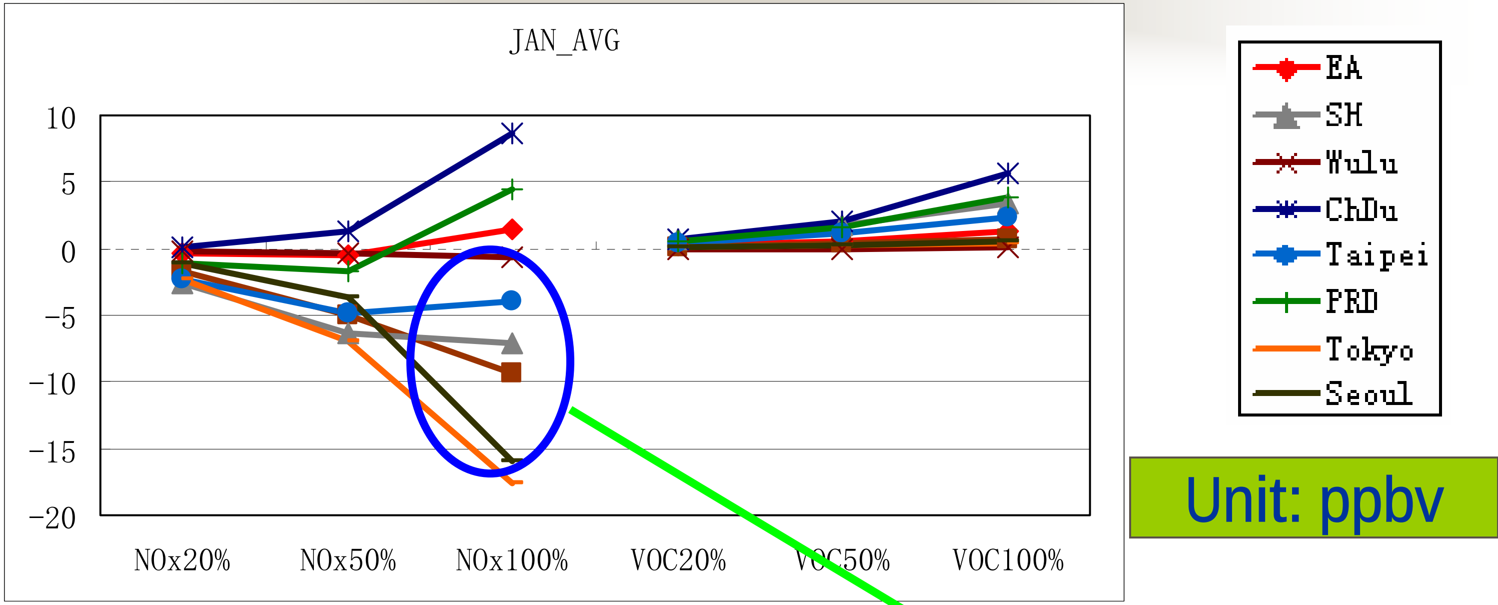


VOC and NOX Sensitivity Analysis

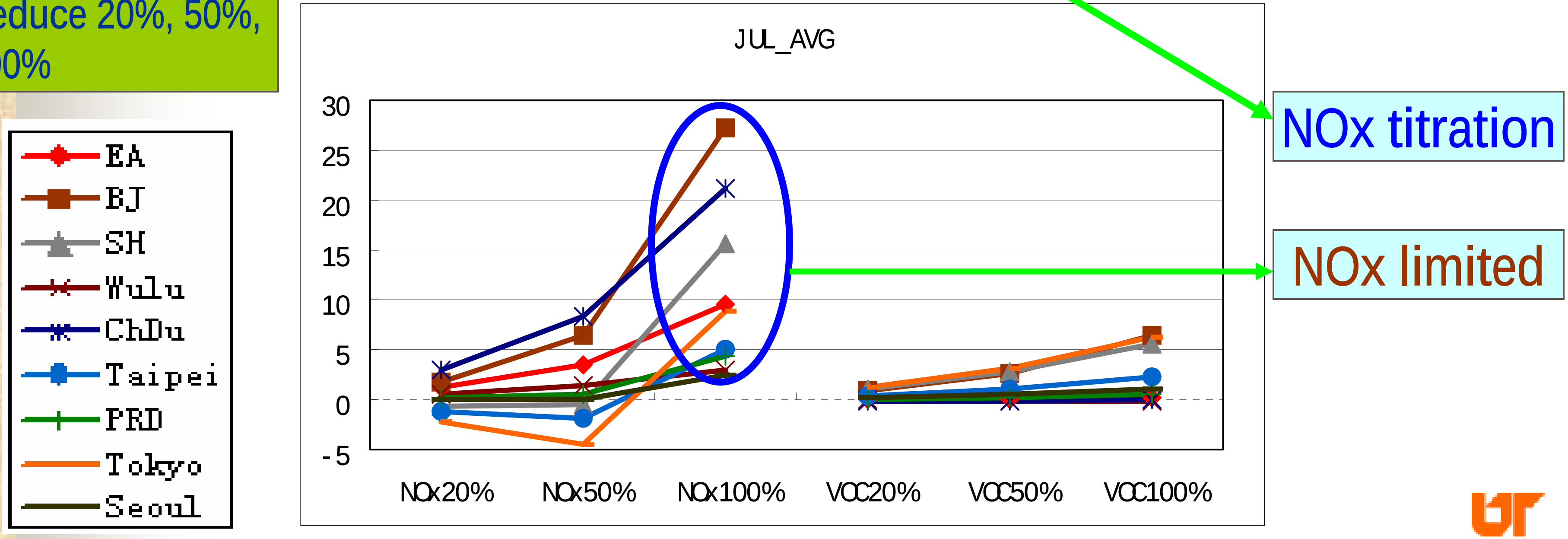
Compare difference between base case and sensitivity case

NOx:
Reduce 20%, 50%, 100%

Anthropogenic VOCs:
Reduce 20%, 50%, 100%



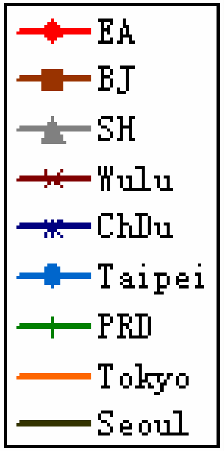
Unit: ppbv

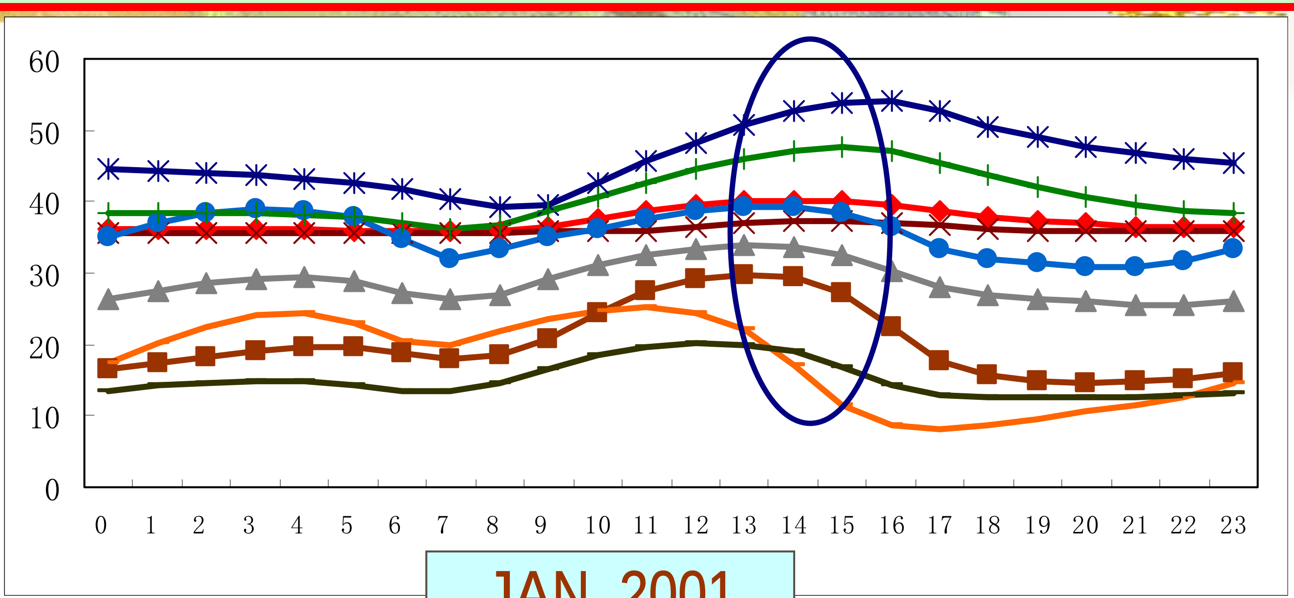


Ozone diurnal variation

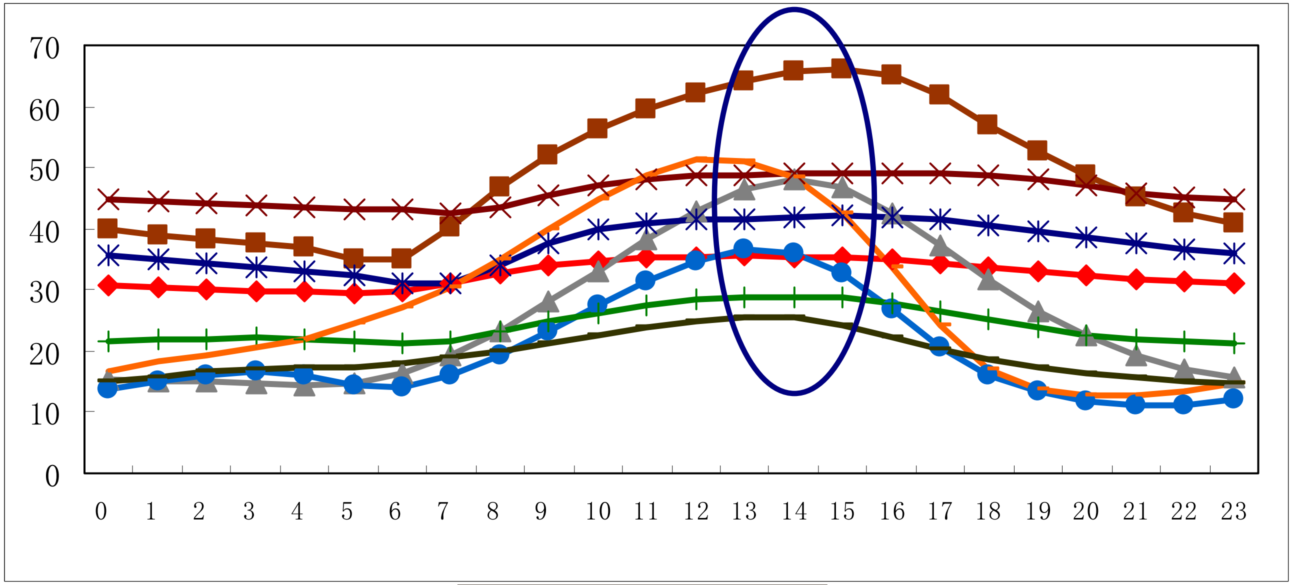
Each hour is monthly mean value

Unit: ppbv





JAN, 2001



JUL, 2001

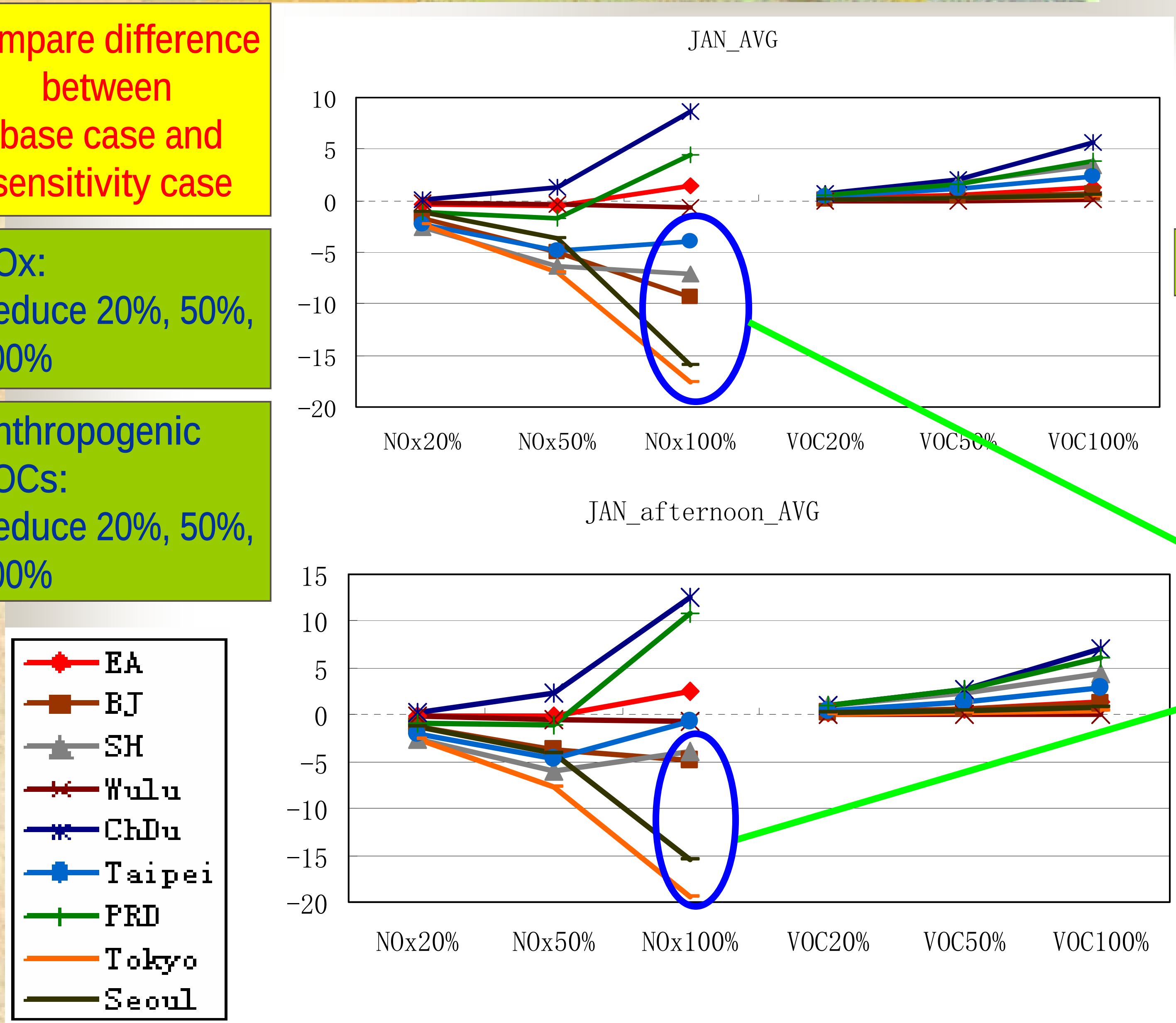
VOC and NOX Sensitivity Analysis

Compare difference between base case and sensitivity case

NOx:
Reduce 20%, 50%, 100%

Anthropogenic VOCs:
Reduce 20%, 50%, 100%

Unit: ppbv

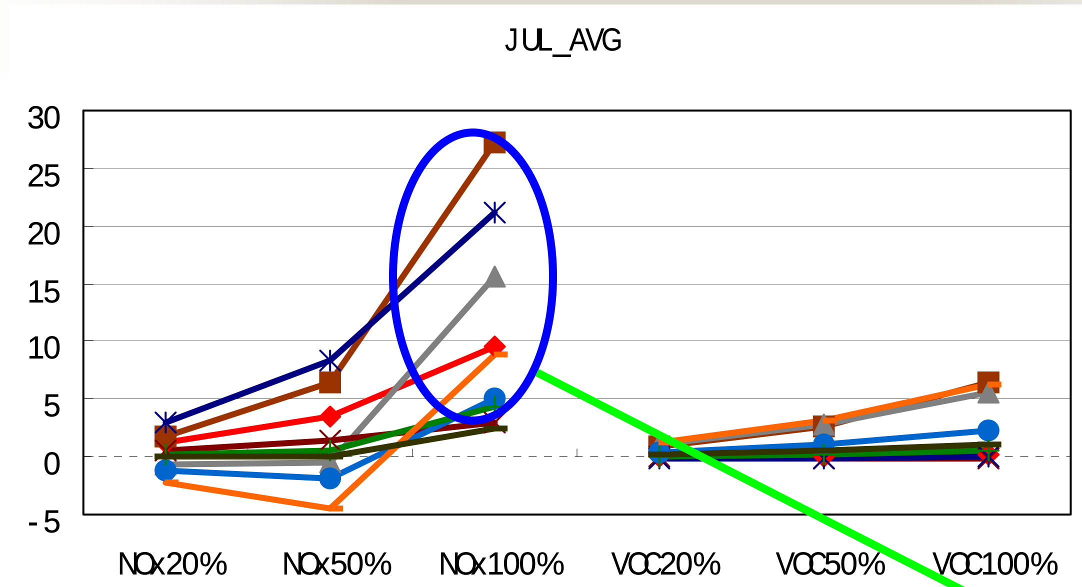


NOx titration

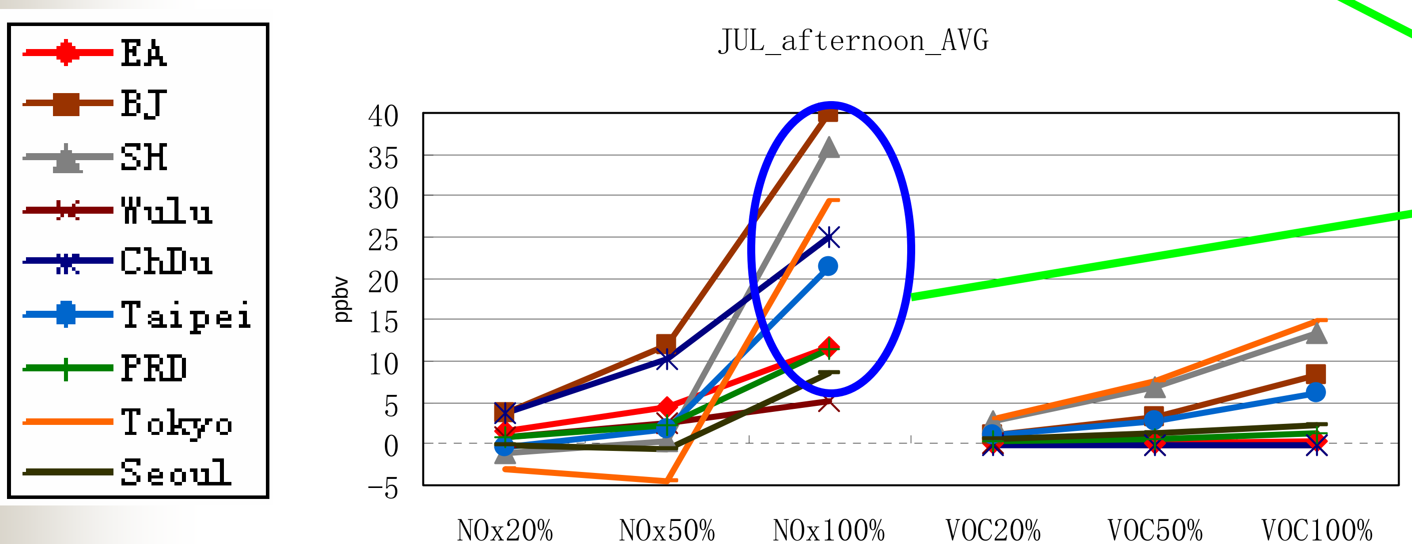
Impacts from both of VOCs and NOx become larger among afternoon

VOC and NOX Sensitivity Analysis

Impacts from VOCs in month afternoon average can reach 3 times as monthly average

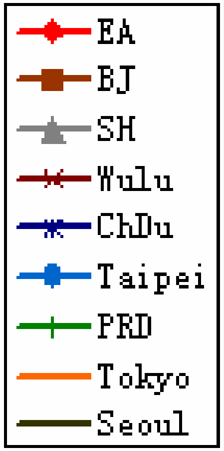


Unit: ppbv



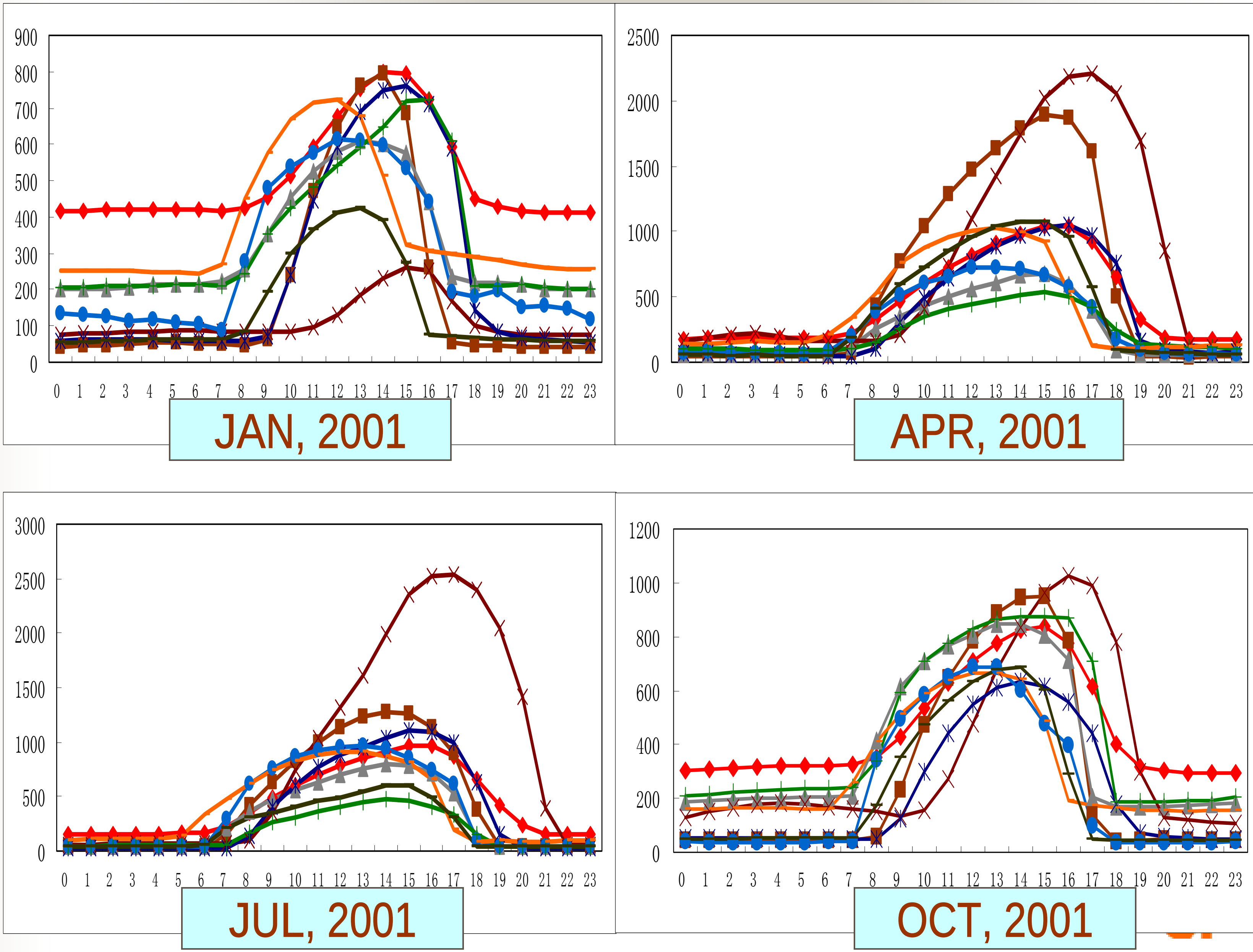
NOx limited

PBL Height



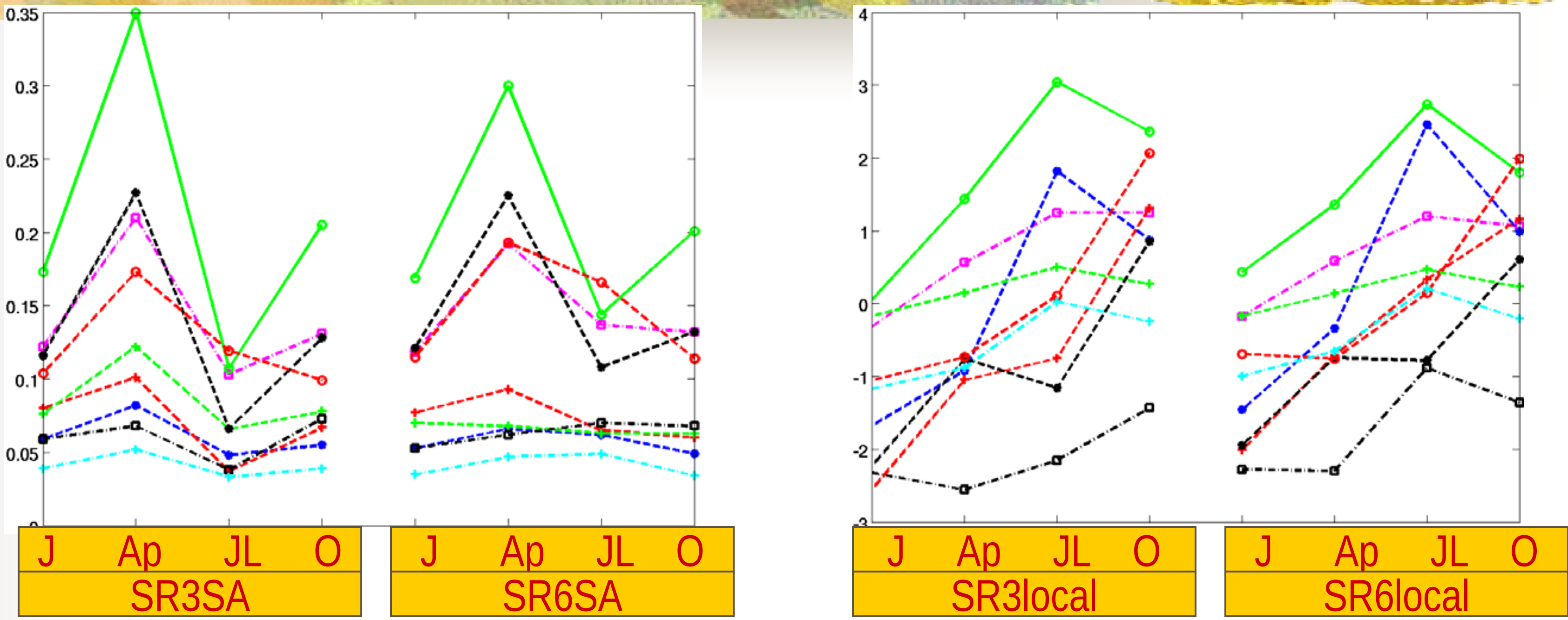
Unit: Meter

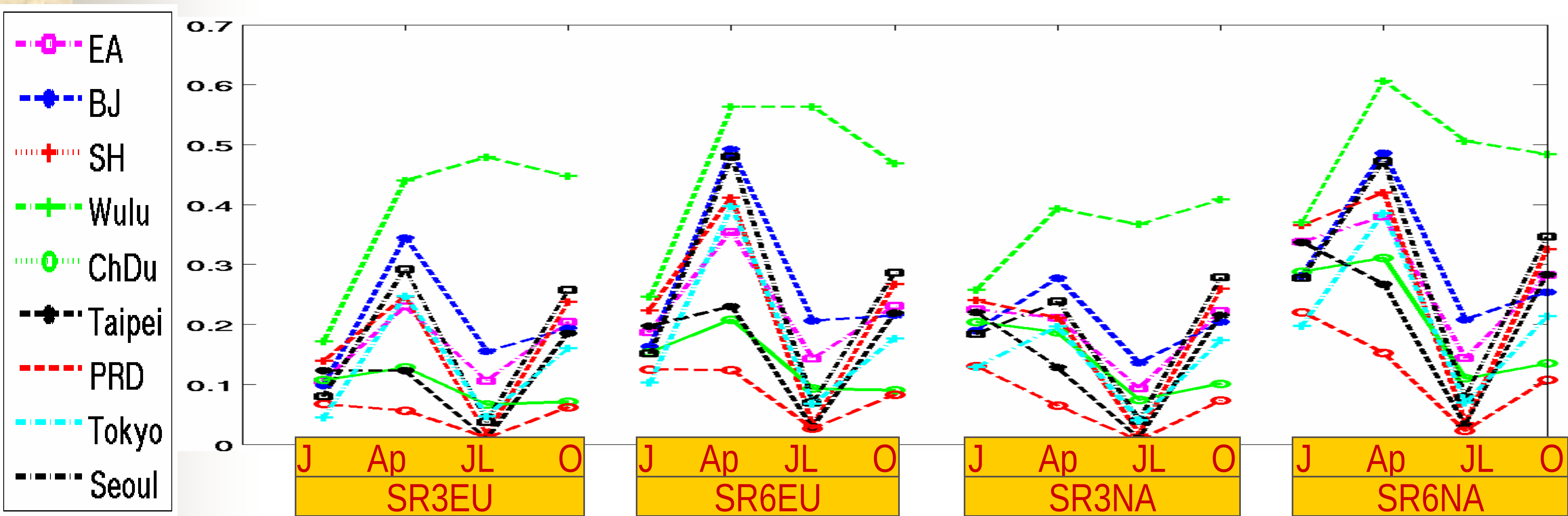
Each hour is monthly mean value



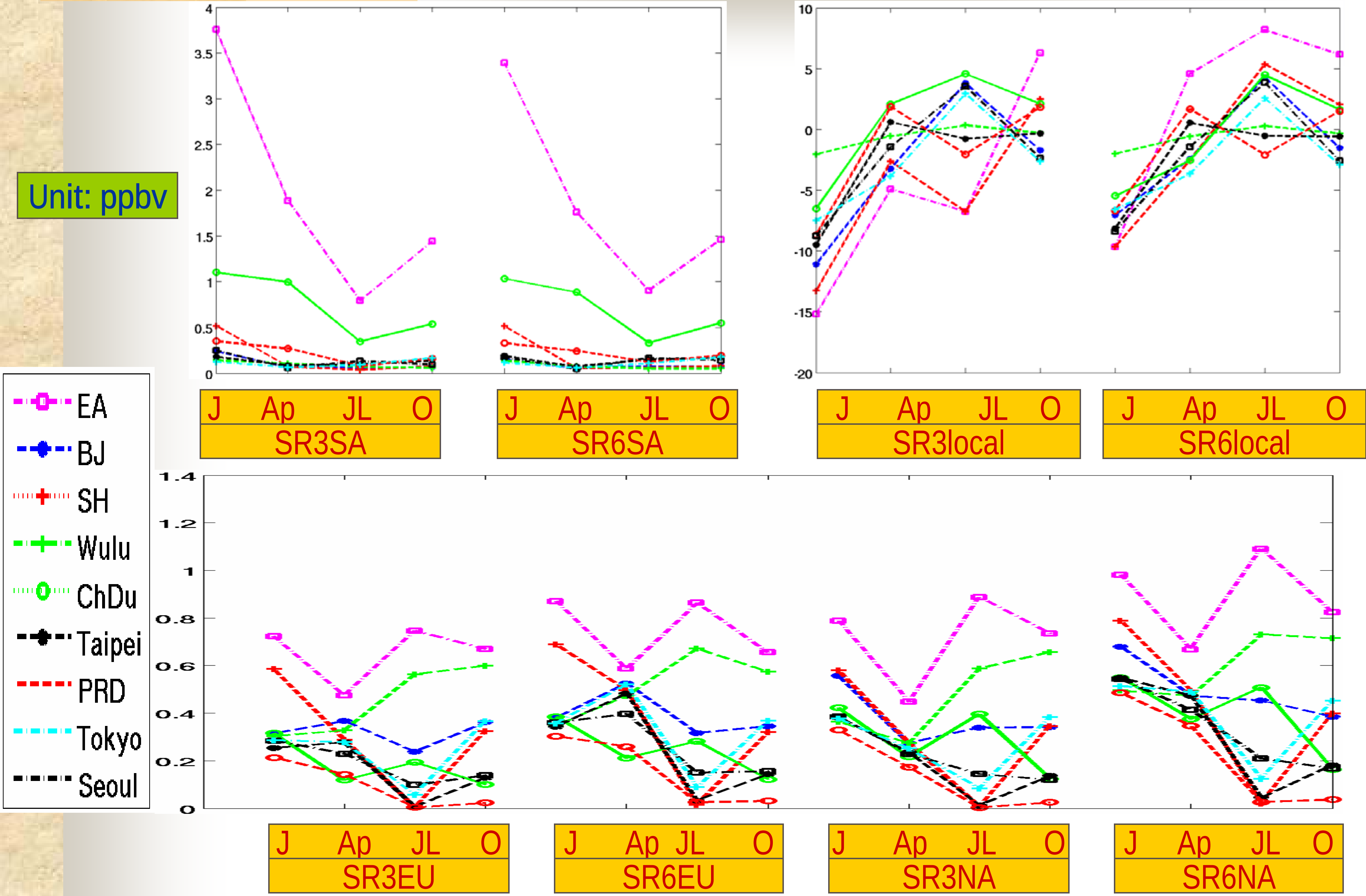
Monthly average surface ozone impact on EA from other sources

Unit: ppbv



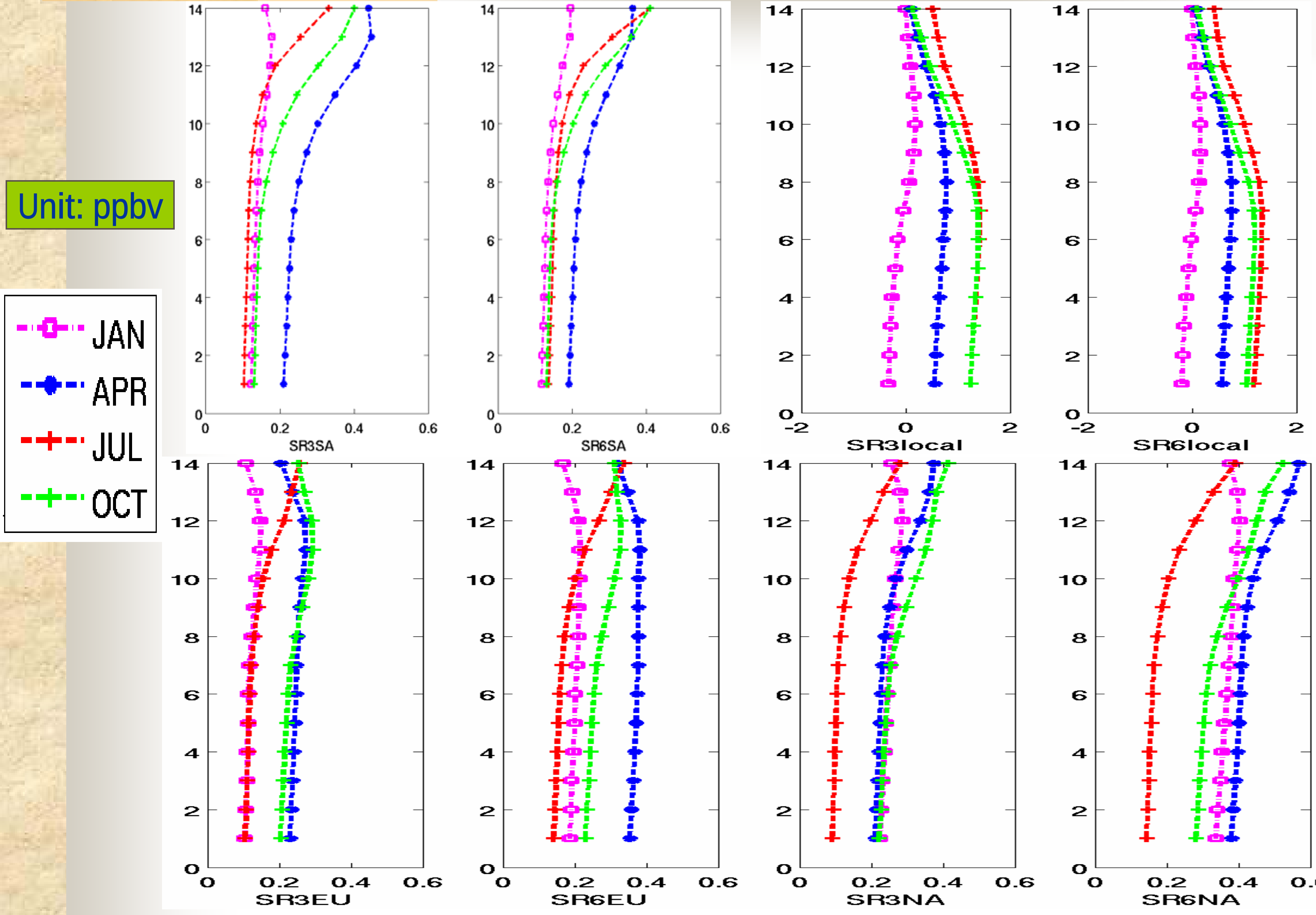


Monthly maximum Surface ozone impact on EA from other sources

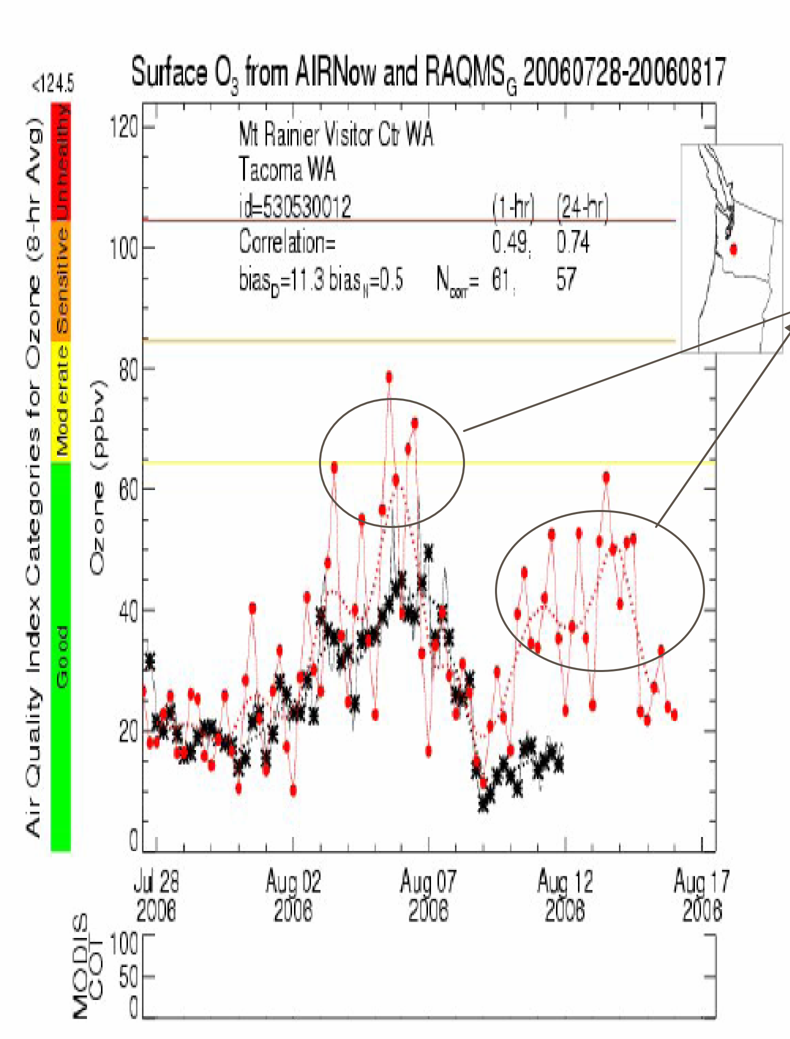


Monthly average vertical ozone impact on EA from other sources

Unit: ppbv



Effect of using Global Chemistry Model for CMAQ IC/BC



"the simulation shows good agreement with ozonesonde data aloft, but leads to O3 overestimation near surface. The performance inconsistency implies that CMAQ could overestimate the vertical mixing and bring too much ozone downward.

*** Tang, Y. H., et al. (2008) CMAQ predictions of tropospheric ozone over the continental United States. Environ Fluid Mech.**

This mostly like cause by the stratospheric ozone in GCM IC/BC

Ai-Saadi, J., Pierce, B.,et al., (2007) Global Forecasting System (GFS) Project: Improving National chemistry forecasting and assimilation capabilities. Applications of Environmental Remote Sensing to Air Quality and Public Health, Potomac, MD.

Chemistry Model Downscaling

GEOS-Chem

- **Domain:** Global
- **Horizontal Grid Spacing:** 2° x 2.5°
- **Horizontal Coordinate:** Lat x Lon
- **Vertical Grid Spacing:** 30 layers
- **Simulation Period:** 2001, 2002
- **Meteorological Input:** GEO3, GEO4

→

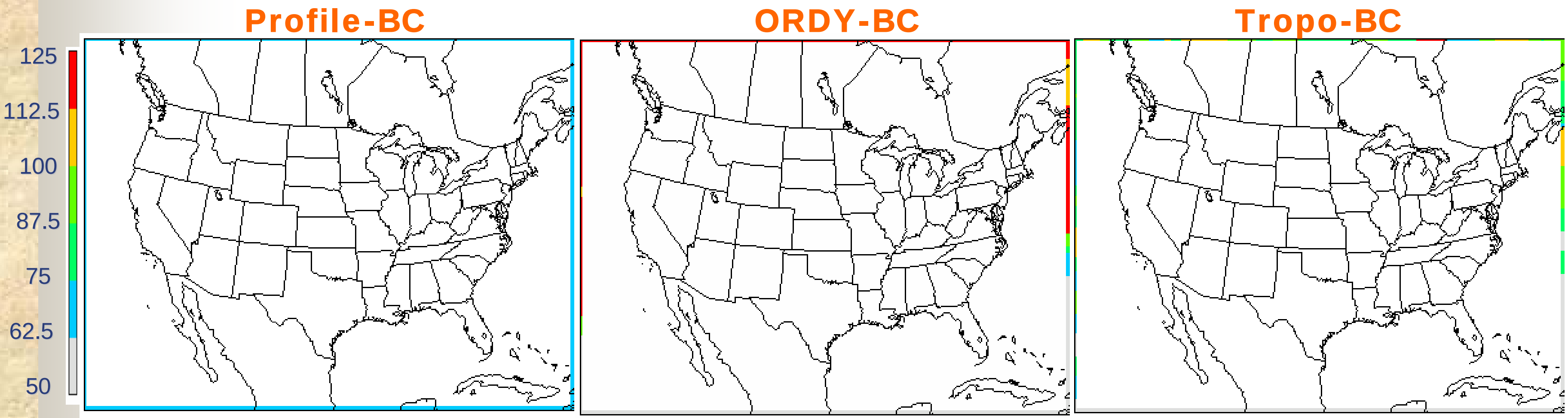
CMAQ

- **CMAQ Model Version:** 4.5
- **Emissions: scenario** VISTAS 2002
- **Model Domain:** CONUS
- **Horizontal Grid Resolution:** 36-km
- **Vertical Grid Spacing:** 19 layers
- **Simulation Period:** JAN, JUN & JUL, 02

2002 CMAQ Scenarios – Jan, Jun & Jul

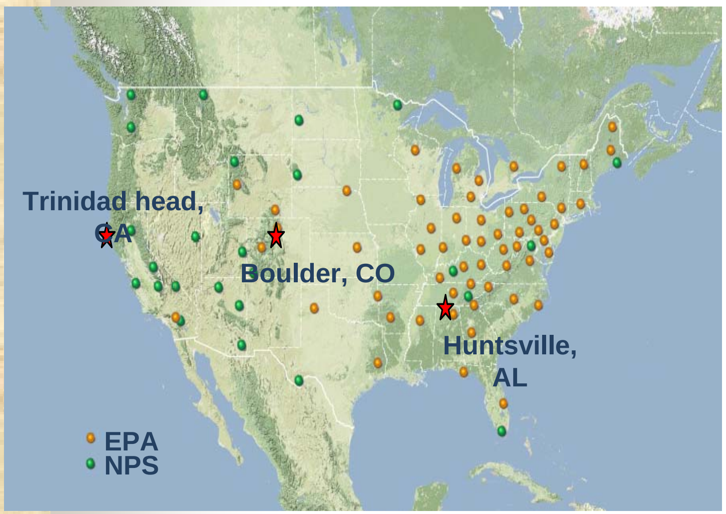
Three IC/BC scenario

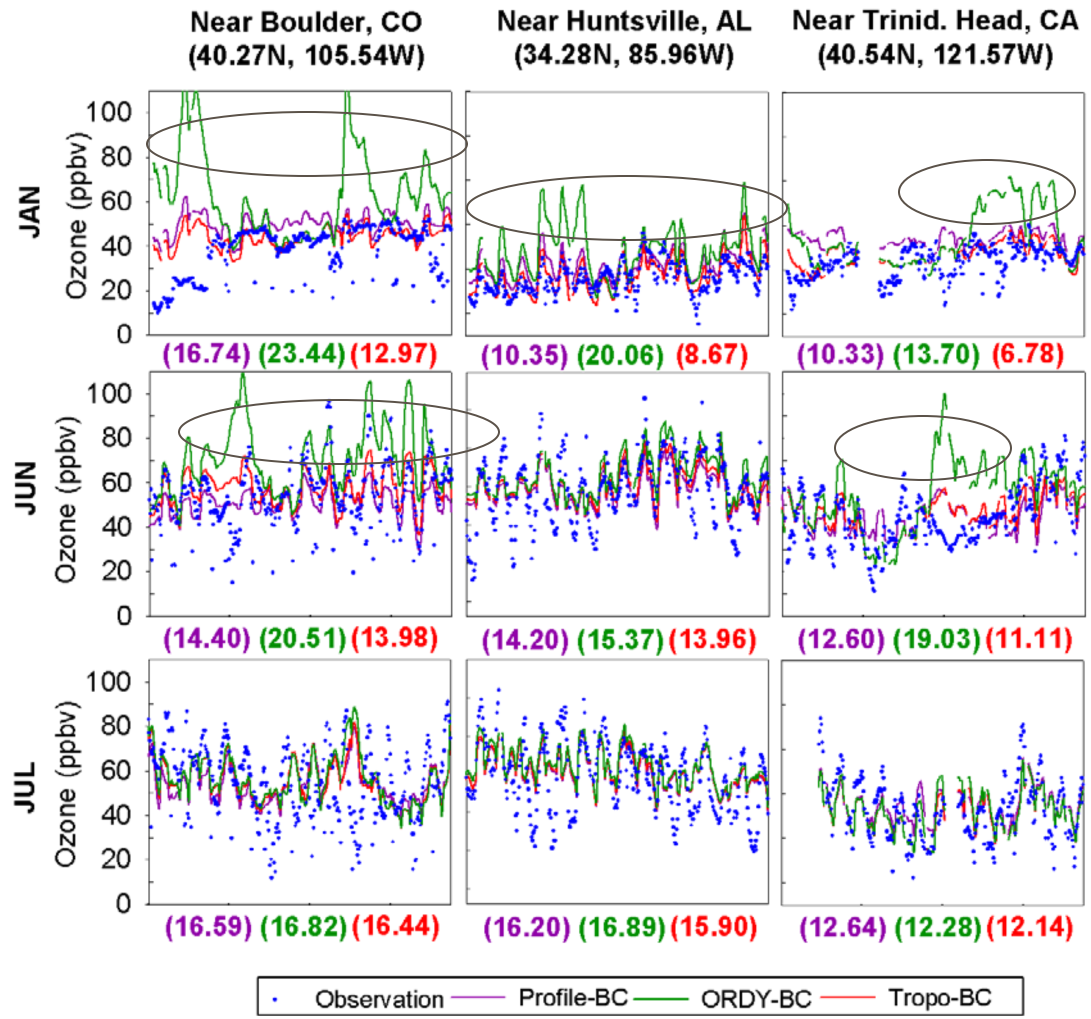
1) Profile-IC/BC (Profile-BC)
   Standard EPA fixed profile
2) ORDY-IC/BC (ORDY-BC) – using GEOS-Chem output
   Elevation/pressure interpolation method
3) Tropopause Interpolation IC/BC (Tropo-BC)- using GEOS-Chem output
   Apply tropopause as part of the criteria



Observation Vs. Simulated Value

2002 – CASTNET data
(surface observation)





(ellipse) → Overestimate

( ) → Root Mean Square Error

2002 Statistical Output – Jan, Jun & Jul

		Profile-BC	ORDY-BC	Tropo-BC
JANUARY	ALL	**RMSE = 11.9 ppbv**	**RMSE = 19.8 ppbv**	**RMSE = 10.3 ppbv**
		MB = 7.3 ppbv	MB = 13.2 ppbv	MB = 3.9 ppbv
	WEST	**RMSE = 16.8 ppbv**	**RMSE = 23.5 ppbv**	**RMSE = 13.0 ppbv**
		MB = 14.6 ppbv	MB = 18.3 ppbv	MB = 9.8 ppbv
	CENTRAL	**RMSE = 10.1 ppbv**	**RMSE = 23.6 ppbv**	**RMSE = 8.2 ppbv**
		MB = 6.6 ppbv	MB = 16.1 ppbv	MB = 2.4 ppbv
	EAST	**RMSE = 11.2 ppbv**	**RMSE = 18.0 ppbv**	**RMSE = 10.1 ppbv**
		MB = 6.3 ppbv	MB = 11.5 ppbv	MB = 3.2 ppbv
JUNE	ALL	**RMSE = 14.3 ppbv**	**RMSE = 16.4 ppbv**	**RMSE = 13.8 ppbv**
		MB = 0.3 ppbv	MB = 7.2 ppbv	MB = 1.9 ppbv
	WEST	**RMSE = 18.3 ppbv**	**RMSE = 19.9 ppbv**	**RMSE = 15.2 ppbv**
		MB = 4.3 ppbv	MB = 7.2 ppbv	MB = 2.0 ppbv
	CENTRAL	**RMSE = 12.5 ppbv**	**RMSE = 16.0 ppbv**	**RMSE = 11.3 ppbv**
		MB = -4.5 ppbv	MB = 6.1 ppbv	MB = -1.3 ppbv
	EAST	**RMSE = 14.1 ppbv**	**RMSE = 15.9 ppbv**	**RMSE = 14.1 ppbv**
		MB = 1.1 ppbv	MB = 7.6 ppbv	MB = 2.9 ppbv
JULY	ALL	**RMSE = 16.3 ppbv**	**RMSE = 16.6 ppbv**	**RMSE = 15.8 ppbv**
		MB = 4.2 ppbv	MB = 5.3 ppbv	MB = 3.4 ppbv
	WEST	**RMSE = 19.8 ppbv**	**RMSE = 16.9 ppbv**	**RMSE = 16.9 ppbv**
		MB = 4.3 ppbv	MB = 6.0 ppbv	MB = 4.1 ppbv
	CENTRAL	**RMSE = 13.7 ppbv**	**RMSE = 13.7 ppbv**	**RMSE = 13.3 ppbv**
		MB = -2.4 ppbv	MB = -1.4 ppbv	MB = -3.1 ppbv
	EAST	**RMSE = 16.4 ppbv**	**RMSE = 17.3 ppbv**	**RMSE = 16.3 ppbv**
		MB = 6.2 ppbv	MB = 8.1 ppbv	MB = 6.1 ppbv

ALL - All stations; WEST - West of 115W; CENTRAL - Between 115W and 94W; EAST - East of 94W

RMSE is root mean square error; MB is mean bias

- **Tropo-BC** always the best
- The most improvement occurred on **January**
- **“WEST”** got the largest improvement for all three months, about **3 - 4 ppbv in RMSE**
- Minor improvement observed in both **“CENTRAL”and“EAST”**

Summary

- The effects of European/South Asia emissions as CMAQ boundary conditions and Local emissions were demonstrated by the CMAQ simulation results in 36-km regional scale and seasons in this study.
- Significant effects were observed due to local emissions. Also, Higher effect were found at mid-high latitude on both SR3EU&SR6EU cases. Meanwhile, the effects of SR3SA&SR6SA cases do not affect as large area as SR3EU&SR6EU which seems caused by the high terrain.
- The effect is accumulating and transporting with time and seems more significant in April and October (monthly average) than in January and July for the boundary impact, while the local impact are more obvious in July. (seasonal effects)
- The maximum boundary effect on the regional scale is in range from 0-4 ppb. The maximum local effect is between -15 and 9ppb, which is much large than the regional effect and also has obvious VOC and NOx limited appearance.
- In VOC limited areas such as megacities cities Beijing, Shanghai, Tokyo and Seoul, NOx reduction may lead to increase of ozone concentrations, which is hard for global model to catch up due to coarse resolution. It suggests that finer resolution simulations should be conducted to analyze transport effects between transport and regional/local influences.
- Higher ozone concentrations in surface levels could be caused by initial conditions and boundary conditions in vertical downscaling at high altitude (the top layers of regional models) from global models. Fu et al. (CMAS, 2008).

Acknowledgment And Collaboration

- USEPA STAR funding support
- USEPA OAQPS ICAP Project
- Harvard University
- USEPA ORD ASMD
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